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# Lantana invasion alters soil nitrogen pools and processes in the tropical dry deciduous forest of India

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ABSTRACT

Invasive species can alter the soil nutrient pools and processes in ecosystems that they invade by altering the quality and quantity of litter inputs. Studies have shown the impact of vegetative understory invasions on soil nitrogen (N) availability in forest ecosystems. In the dry deciduous Vindhyan forest of India we studied the effect of one of the world's most noxious weeds, lantana (*Lantana camara* L.) on soil N availability and N-mineralization beneath the forest canopy and lantana canopy. We observed that the lantana litter inputs increase with increasing lantana cover and the chemical composition of lantana litter was also very much different from the native forest species litter. High N, low lignin content of the lantana litter and favorable microclimate beneath lantana canopy favored faster decomposition and release of N. This alteration in litter inputs and chemistry beneath the lantana canopy positively and significantly altered soil N availability, N-mineralization, and total soil N. The results imply that a positive feed back nutrient cycle might exist beneath the lantana canopy which may favor its growth (cover) by increasing the nutrients beneath its canopy.



## 1. Introduction

Invasive plant species are commonly recognized to have severe ecological impacts in a wide range of ecosystems throughout the world (Vitousek et al., 1996; Levine et al., 2003). The study of conditions facilitating invasions and the consequences of invasion offer insight into fundamental questions in ecology and evolution (Vitousek et al., 1987; Vitousek, 1990; Crawley et al., 1999), and is of great practical importance in providing a better understanding of the threat to ecological communities.

Invasive species can alter ecosystem function by changing disturbance frequency or intensity (D'Antonio and Vitousek, 1992; Fensham et al., 1994; Smith, 1994; Mullett and Simmons, 1995), altering trophic structure (Cross, 1982; Hobbs and Mooney, 1986; Braithwaite et al., 1989) and changing resource availability (Vivrette and Muller, 1977; Vitousek and Walker, 1989; Boswell and Espie, 1998). Among these factors, disturbance may favour invasions by disrupting strong competitive-species interactions (Fox and Fox, 1986; Crawley, 1987) and locally increasing different limiting resources (Hobbs, 1989).

Numerous mechanisms have been identified by which plants can alter physical, chemical and biological properties of the soil (Binkley and Sollins, 1990; Chapin et al., 1996; Finzi et al., 1998a,b). Invasive species' effects on nitrogen (N) cycling have long been studied (Scott et al., 2001; Mack et al., 2001; Asner and Beatty, 1996) but they mainly focus on N-fixing species that tend to increase N pools (Stock et al., 1995; Yelenik et al., 2004, 2007). However, certain species alter the soil nutrient pools by altering the quality and quantity of litter inputs. Plant-mediated changes in soil properties following exotic invasion are little documented. Vitousek (1990) first pointed out that exotic species could alter soil processes, and identified differences in resource acquisition and utilization by exotic plant as the mechanism driving changes in soil-based processes. However, changes in soil-biogeochemistry following a shift in species composition could be another pathway of change. Either of the mechanisms could allow introduced species to create a feed back system (Wilson and Agnew, 1992). Such changes in soil ecology either accelerate the exotic's own growth or promote its competitive superiority to native species; a positive feedback system could develop that promotes the spread of the exotic. The changes in decomposition and nutrient cycling associated with invasions may have positive impacts on nutrient availability that can in turn lead to greater decomposition rates (Hobbie and Vitousek, 2000) and thus further increase the amount of nutrients and rate at which they are cycled through the ecosystem. Thus increased nutrient availability will favor faster growing, higher productivity species and in particular may favour

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establishment of fast growing invaders over slower growing native species (Dukes and Mooney, 1999).

Despite the recent recognition of the importance of invasive species there are many areas of the world lacking basic information on altered ecosystem functioning by invasive plants (Sharma et al., 2005a). For example, no information is available for the effect of invasive plant species on the functioning of dry tropical forests of India. The candidate species selected was *Lantana camara* L. (referred as lantana hereafter) as this noxious species has spread extensively throughout the dry deciduous forests of India (Sharma et al., 2005b; Raizada et al., 2008). Lantana was introduced in the early nineteenth century as an ornamental plant (Sharma, 1988), but it is recognized as a major threat to the biodiversity of the region (Sharma et al., 2005b). Still, soil functional changes caused by lantana invasion have not been addressed in dry tropical forest areas of India.

Based on the ideas above we hypothesize that invasion of lantana alters litter quantity, quality, decomposition, mineralization and the subsequently influence the N cycling in a N limited tropical dry deciduous forest of India. To test this hypothesis, we evaluated the response of litter quality, quantity, decomposition and N-mineralization beneath the forest canopy and lantana canopy in a dry deciduous forest of India. The study was divided into following studies and a experiment: (a) estimation of lantana cover and litter inputs; (b) estimation of chemical properties of the litter; (c) estimation of physico-chemical properties of the soil beneath forest canopy and lantana canopy, at the start of the experiment and at the end; (d) litter decomposition beneath forest canopy and lantana (>50%) canopy; and (e) N-mineralization estimation under forest canopy and under lantana canopy (high: >50% and medium: <50% cover) locations.

## 2. Materials and methods

### 2.1. Study site

The study was conducted in the Vindhyan dry deciduous forest region (24°13′ to 24°19′ N; 83°59′ to 83°13′ E) in the year 2005–2006. The elevation above the mean sea level ranges between 313 and 483 m. The climate is tropical with three seasons in a year, i.e. summer (March to mid-June), rainy (mid-June to September) and winter (October to February). The soils are Ultisols, sandy loam in texture and reddish to dark grey in colour and are extremely poor in nutrients (Singh et al., 1989). The potential natural vegetation of the region is tropical dry deciduous forest, which is locally dominated by species such as *Anogeissus latifolia*, *Boswellia serrata*, *Buchanania lanzan*, *Diospyros melanoxylon*, *Hardwickia binata*, *Lagerstroemia parviflora*, *Lannea cormendelica*, *Madhuca longifolia*, *Shorea robusta* and *Terminalia tomentosa* (Sagar et al., 2003). The study was established in locations dominated by the above mentioned tree species. Three locations under forest canopy (no-lantana/lantana free locations) and six locations with-lantana as a dominant understory were chosen for the study [with 3 locations at high (>50%) and 3 locations at medium (<50%) lantana cover, respectively]. All locations chosen had similar environments and land-use histories.

### 2.2. Lantana cover and litter inputs

Lantana cover was estimated at 12 random sub-locations (locations with-lantana) using the Domin Krajina scale and was transformed into percentage cover for final analysis. Lantana cover was taken as the percentage of the ground surface covered by the shadow of the lantana foliage, estimated as <1, 5, 10, 30, 50, 60, 75, 90, >95% [with this classification, some locations within lantana were classified as high (>50%) and medium (<50%) lantana cover] (Müller-Dombois and Ellenberg, 1974). Litter fall beneath the lantana canopy was quantified at these 12 randomly selected sub-locations during the period of April when maximum litter fall beneath the lantana is encountered (personal observation). Three litter traps of 50 cm × 50 cm × 15 cm were placed randomly (≈1–3 m from the main stem) beneath these 12 lantana canopies from which the litter was collected (mean values expressed). The litter samples were oven dried at 60 °C to constant weight. Forest litter (litter from above mentioned dominant tree species) was also collected under forest canopy (no-lantana) locations.

### 2.3. Plant analysis

Lantana litter (LL), forest litter (FL) (similar proportions for all the dominant canopy tree species mentioned) and mixed litter (ML) (50% lantana + 50% other forest species litter) was estimated for some chemical characteristics initially. Total N in plant litter were measured by the micro-kjeldahl method (Jackson, 1958) and carbon content (C) of the litter was estimated by loss on ignition method (Mcbrayer and Cromack, 1980). Ethanol soluble substances were removed from the litter by extracting, 500 mg ground material with 50 ml ethanol (3–30 min). The residual solid material was dried overnight at 105 °C and weighed. The residue was treated with 10 ml 72% $H_2SO_4$ at 30 °C for 1 h. This mixture was diluted with water to 250 ml and refluxed for 2 h. The residual solid material was filtered, washed with water, dried overnight at 105 °C and weighed. The cellulose content (Celu) was estimated as loss in weight by acid treatment. The amount of lignin (L) (Klason lignin, Effland, 1977) was determined as the mass loss on ignition of the acid insoluble residue.

### 2.4. Soil analysis

Three samples from the first 10 cm of soil were randomly obtained in autumn 2005 under forest canopy (no-lantana) location. From locations beneath lantana canopy, three soil samples were taken beneath high (>50%) and medium (<50%) lantana cover, respectively. Considering that lantana roots can spread to 5 m in diameter, we took soil samples representing areas just beneath the lantana canopy and the same distance under forest canopy (Zinke, 1962). A total of nine soil samples were analyzed for total C, total N, pH, soil moisture (Sm), and particle size fractions. The sampling for total C and total N was repeated at the end of the experiment to see the alteration in the nutrients (C*i* = initial, C*f* = final, N*i* = initial and N*f* = final). The soils were sieved through 2 mm mesh screen, fine roots were removed, and the samples were transported to the laboratory for further analysis. Soil pH (1:2.5::soil:water) was determined by digital pH meter, organic carbon was measured by Walkey and Black rapid titration method (Jackson, 1958) and total N by Gerhardt Kjeldal analyzer (Gerhardt Gmbh, Germany). Samples were analysed for sand, silt and clay fractions by the hydrometer method (Bowles, 1988). Soil moisture was measured in the field condition using the Theta probe (Delta-T devices Ltd., England). Bulk density and water holding capacity was measured using the Piper (1944) method.

### 2.5. Decomposition of lantana, forest and mixed litter

Litter decomposition rates and patterns of N dynamics in decomposing litter were measured using the litterbag method in the field. Experiments lasted for approximately 1 year. Litter was air-dried to a constant weight and exactly 3 g of litter was placed into 10 cm × 10 cm polyethylene bags with a mesh size of 0.3 mm. Litterbags of only lantana (LL), mixed (ML) (50% lantana + 50% other forest species litter) and forest species litter (FL) were placed on the soil surface beneath the lantana canopy

(only at locations with >50% lantana cover) and under forest canopy (no-lantana). Care was taken to place the bags beneath the forest and lantana canopy, where soil samples were collected initially. Nine samples (three of each litter type) were collected from soil surface beneath the lantana canopy and nine samples under forest canopy locations.

Sufficient bags were used to allow for the harvest of 3–4 replicates of lantana, mixed and forest litter of other species at 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, and 360 days. After collection, the litter was rinsed with water and fresh roots and soil fauna were removed. Litter samples were dried, weighed and prepared for nutrient analysis every 60 days. From the litterbag study, annual decay rate constants were calculated (mean values used) assuming a negative exponential model (Olsen, 1963): $W_t/W_0 = \exp^{(-kt)}$; where $W_0$ = initial mass and $W_t$ = mass remaining after time interval $t$. The time required for 50% and 95% mass loss was calculated as: $t_{50} = 0.693/k$ and $t_{95} = 3/k$.

### 2.6. N-mineralization

N-mineralization was measured at same three locations where soil was sampled (under forest canopy, under medium (<50%) and high (>50%) lantana cover) by in situ buried bag technique (Eno, 1960). A portion of the fresh, field moist soil sample was incubated in the soil at 10 cm depth using sealed polythene bags. Coarse roots and any large fragments of organic debris were removed in order to avoid any marked immobilization during incubation (Ross et al., 1985; Schimel and Parton, 1986). Nitrate N and ammonium N were determined at time zero and after 30 days of incubation for rates. Field moist samples were used for the analysis of nitrate N and ammonium N with in 24 h of sampling. Nitrate N was measured by phenol di-sulphonic acid method (Jackson, 1958) and ammonium N by phenate method (APHA, 1985). The increase in the concentration of nitrate N plus ammonium N over the course of incubation is defined as net N-mineralization (assuming little or no immobilization or gaseous loss).

**Table 1**
Chemical composition of litter.

| Litter | C% | N% | C:N | L% | Celu% | L:N |
|---|---|---|---|---|---|---|
| LL | 42.4 a[a] | 2.2 a | 18.9 a | 10.3 a | 33.5 a | 4.6 a |
| FL | 45.8 b | 1.6 b | 29.4 b | 20.0 b | 42.4 b | 12.9 b |
| ML | 43.0 a | 1.8 c | 24.2 c | 15.8 c | 37.1 c | 8.9 c |

[a] Values in columns with the same letter are not significantly different according to Tukey's HSD test at $p < 0.05$. (LL = Lantana litter, FL = Forest litter, ML = Mixed litter).

### 2.7. Statistical analysis

The effect of forest canopy, lantana canopy, and different litter types was analysed by one-way ANOVA. Differences in litter composition, soil physico-chemical properties, available N, rates of ammonification, nitrification and N-mineralization were tested by Tukey's HSD test (at $p < 0.05$). Linear correlation regression was used wherever necessary. All statistical analyses were performed using the SPSS (SPSS Inc., Chicago, USA) statistical package (SPSS, 1997).

## 3. Results

### 3.1. Chemical composition of litter

The lantana litter inputs significantly increased with increasing lantana cover ($r^2 = 0.9211$; $p = 0.001$, $n = 12$). The different litter inputs showed varying chemical composition (Table 1). Lantana litter showed higher N, lower cellulose and lignin contents compared to mixed and forest litters. As a result C:N and lignin:N, ratios were lower in lantana litter. Interestingly,

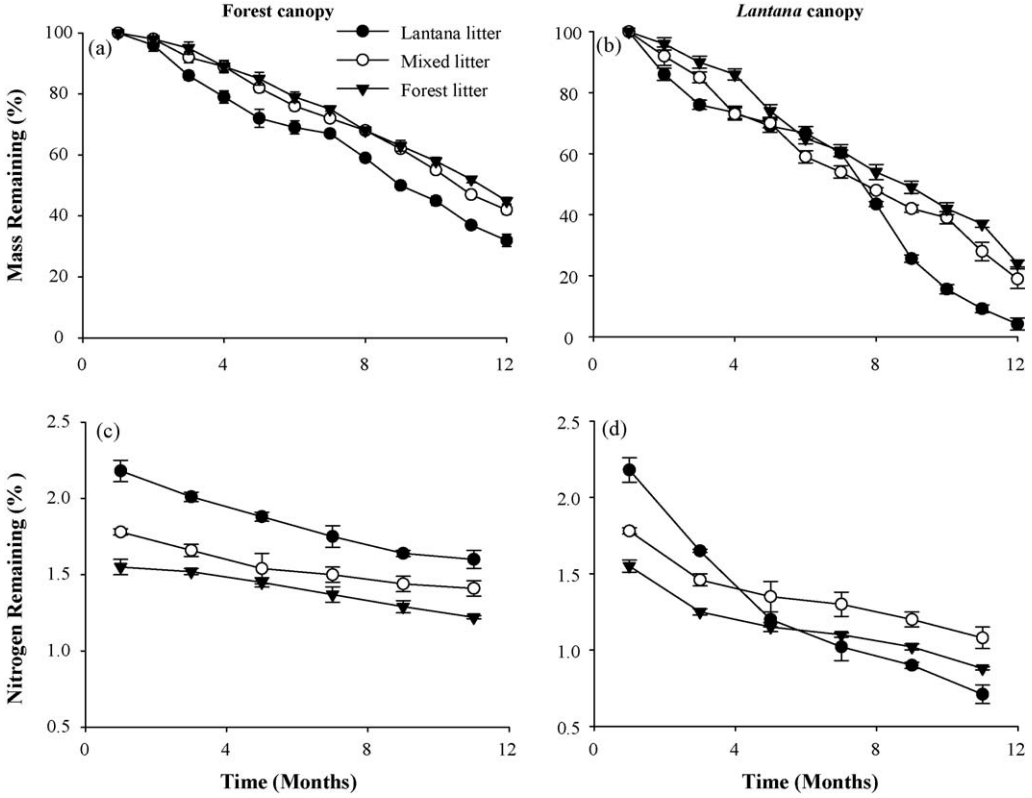


**Fig. 1.** Percentage mass remaining and total litter nitrogen with time of the three litters (lantana litter, mixed litter and forest litter) beneath the forest canopy and lantana canopy (The error bar represents ± S.E.).

**Table 2**
Decay rate constant ($k$), and estimated time required for 50% ($t_{50}$) and 95% ($t_{95}$) mass loss for different litters.

| Location | $k$ (day$^{-1}$) | $t_{50}$ (day) | $t_{95}$ (day) |
|---|---|---|---|
| Lantana canopy (>50%) | | | |
| LL | 0.0038 | 181 | 784 |
| FL | 0.0020 | 402 | 1742 |
| ML | 0.0017 | 342 | 1479 |
| Forest canopy | | | |
| LL | 0.0013 | 504 | 2182 |
| FL | 0.0009 | 719 | 3112 |
| ML | 0.0010 | 662 | 2865 |

LL = Lantana litter, FL = Forest litter, ML = Mixed litter.

ANOVA indicated significant differences in total carbon (C) ($F_{2,\ 6} = 36.16$, $p < 0.0001$), total N($F_{2,\ 6} = 119.8$, $p = <0.0001$), lignin ($F_{2,\ 6} = 248.4$, $p = <0.0001$), cellulose ($F_{2,\ 6} = 90.2$, $p = <0.0001$), lignin:N ($F_{2,\ 6} = 183.8$, $p = <0.0001$) and C:N ratio ($F_{2,\ 6} = 103.2$, $p = <0.0001$) in three different litter types.

### 3.2. Decomposition of different litters

Percent mass remaining data indicated widely different rates of decomposition of different litter inputs under forest (Fig. 1a) and lantana canopy (Fig. 1b). The estimated instantaneous decay rate constant ($k$ value day$^{-1}$) of lantana, was greater than the $k$ value of forest litter and mixed litter (Table 2) beneath lantana canopy (>50%). The estimated $k$ value (day$^{-1}$) of lantana, was greater than the $k$ value of forest litter and mixed litter (Table 2) beneath forest canopy, but lower than beneath lantana canopy (Table 2). Indicating that decomposition of litter takes place faster beneath lantana canopy. After 360 days, beneath the lantana canopy, ca. 4% of lantana litter remained undecomposed compared to 19% and 24% for mixed litter and forest litter (Fig. 1b). But only 32% of lantana litter decomposed compared to 42% and 45% for mixed litter and forest litter, respectively under forest canopy (Fig. 1a). This was also evident from the $t_{50}$ and $t_{95}$ values of litter mass loss beneath lantana canopy and forest canopy (Table 2). High N and low lignin containing lantana litter having low lignin:N and C:N ratio (Table 1) decomposed rapidly ($k = 0.038$) beneath the lantana canopy (Tables 1 and 2) as compared to the forest ($k = 0.0020$) and mixed ($k = 0.0017$) litter. The % litter N remaining followed a similar pattern to total decomposition, with N loss occurring more quickly beneath lantana canopy (Fig. 1c and d). Significant positive correlation between lantana cover and soil N availability, lantana litter inputs and soil N availability ($r^2 = 0.72$, $p = 0.04$ and $r^2 = 0.81$, $p = 0.02$, respectively) was observed in this study.

### 3.3. Soil

The summary of the physico-chemical characters of soil are compiled in Table 3. There was a positive and significant correlation between, total soil carbon, total N (initial and final) and N-mineralization (Table 4). Various soil physical parameters did not differ significantly beneath the lantana canopy and forest canopy, e.g. water holding capacity ($F_{2,\ 6} = 24.1$, $p = 0.08$), bulk density ($F_{2,\ 6} = 2.4$, $p = 0.81$), percentage sand ($F_{2,\ 6} = 0.794$, $p = 0.49$), silt ($F_{2,\ 6} = 0.612$, $p = 0.57$), clay ($F_{2,\ 6} = 0.726$, $p = 0.52$) and pH ($F_{2,6} = 0.845$, $p = 0.55$). Among the soil physical parameters only soil moisture differed significantly ($F_{2,6} = 102.9$, $p = <0.0001$).

Significant differences in total N and total carbon were observed at the start of the experiment [Carbon initial (C*i*): $p = <0.001$; N initial (N*i*): $p = <0.001$) and at the end (Carbon final (C*f*): $p = <0.001$; N final (N*f*): $p = <0.001$], beneath the lantana canopy but it did not alter significantly beneath the forest canopy (Table 3). Total N beneath lantana canopy (>50%) was higher than the soil beneath forest canopy initially and at the end of the experiment (Table 3). Lantana cover was significantly related to total soil

**Table 3**
Summary of soil parameters under forest canopy and lantana [medium (<50%) and high (>50%)] canopy.

| | Forest canopy | Lantana canopy | |
|---|---|---|---|
| | | Medium: <50% | High: >50% |
| Physical characteristics | | | |
| Water holding capacity | 46.6 a[a] | 45.1 a | 45.2 a |
| Soil moisture (%) | 22.6 a | 24.3 b | 31.6 c |
| Bulk density | 1.0 a | 1.0 a | 1.0 a |
| Soil texture (%) | | | |
| Sand | 82.3 a | 83.0 a | 81.1 a |
| Silt | 14.7 a | 15.1 a | 15.0 a |
| Clay | 2.9 a | 2.3 a | 2.4 a |
| Chemical characteristics | | | |
| pH | 6.6 a | 6.5 a | 6.5 a |
| Carbon (%) | | | |
| Initial (C*i*) | 2.30 a | 2.55 b | 2.65 b |
| Final (C*f*)[b] | 2.32 a | 2.75 d | 3.45 e |
| Nitrogen (%) | | | |
| Initial (N*i*) | 0.21 a | 0.25 b | 0.26 b |
| Final (N*f*)[b] | 0.22 a | 0.30 d | 0.34 e |

[a] Values in rows and columns (for carbon and nitrogen %) with different letters are significantly different from each other according to Tukey's HSD test at $p < 0.05$.
[b] At the end of experiment.

**Table 4**
Correlation matrix between various soil parameters and N-mineralization.

| | Sand | Silt | Clay | Sm | C*i* | N*i* | C*f* | N*f* |
|---|---|---|---|---|---|---|---|---|
| Sand | 1 | | | | | | | |
| Silt | −0.52 | 1 | | | | | | |
| Clay | −0.42 | −0.09 | 1 | | | | | |
| Sm | 0.39 | −0.38 | 0.36 | 1 | | | | |
| Ci | 0.50 | −0.26 | 0.25 | 0.84** | 1 | | | |
| Ni | 0.35 | −0.17 | 0.34 | 0.83** | 0.96** | 1 | | |
| Cf | 0.41 | −0.33 | 0.37 | 0.96** | 0.94** | 0.92** | 1 | |
| Nf | 0.36 | −0.16 | 0.32 | 0.85** | 0.97** | 0.99** | 0.93** | 1 |
| N-mineralization | 0.45 | −0.23 | 0.22 | 0.86** | 0.98** | 0.97** | 0.94** | 0.98** |

Sm = soil moisture, C*i* = carbon initial, C*f* = carbon final, N*i* = nitrogen initial and N*f* = nitrogen final.
** Correlation significant at level = 0.01.

**Table 5**
Effect of lantana intensity on the rate of ammonification, nitrification and N-mineralization in a dry tropical deciduous forest (values in parenthesis are ±S.E.).

| | Forest canopy | Lantana canopy | |
|---|---|---|---|
| | | Medium (<50%) | High (>50%) |
| Available N (μg g$^{-1}$) | 19.21 a[a] | 19.76 b | 20.90 c |
| Ammonification rate (μg g$^{-1}$ month$^{-1}$) | 3.34 a | 3.79 b | 3.93 c |
| Nitrification rate (μg g$^{-1}$ month$^{-1}$) | 6.24 a | 7.89 b | 8.72 c |
| N-Mineralization (μg g$^{-1}$ month$^{-1}$) | 9.59 a | 11.69 b | 12.65 c |

[a] Values affixed with different letters were significantly different from each other in row at <0.05.

carbon and total soil N initially (C*i*: $r^2 = 0.85$, $p = 0.05$; N*i*: $r^2 = 0.83$, $p = 0.05$), as well as at the end of the experiment (C*f*: $r^2 = 0.95$, $p = 0.001$; N*f*: $r^2 = 0.91$, $p = 0.00$) but the significance values increased towards the end of the experiment.

### 3.4. N-mineralization rates

Available N varied significantly beneath the forest canopy and lantana canopy ($F_{2,\ 6} = 13.3$, $p = <0.006$). Ammonification ($F_{2,\ 6} = 34.24$, $p = <0.0001$) and nitrification ($F_{2,\ 6} = 106.9$, $p = <0.0001$) rates under forest canopy and lantana canopy also varied significantly. An increasing trend of ammonification and nitrification rates was observed with increasing lantana cover (Table 5). Net N-mineralization rates also went in congruence with the ammonification and nitrification rates and showed increase with increasing lantana cover ($r^2 = 0.93$, $p = 0.001$) and accordingly the N-mineralization rate varied significantly ($F_{2,\ 6} = 151.2$, $p = <0.001$) (Table 5).

## 4. Discussion and conclusions

Our results indicate that the decomposition environment is almost similar beneath the forest canopy and lantana canopy. The sites were of similar soil type, texture and pH suggesting that the variation in decomposition is not caused by physiochemical differences in the soils. Micro-climate may have varied between the locations, affecting decomposition rates. Possibly dense canopy of shrubby lantana could have increased the soil moisture content beneath its canopy (Sharma and Raghubanshi, 2006).

Differences in decomposition and nutrient release rates beneath the forest canopy and lantana canopy resulted from differences in quality and the quantity of litter inputs. The increase in litter inputs with increasing lantana cover implies that altered litter inputs may affect the soil nutrient pools. The effect of plant species on nutrient cycling is determined by both the nutrient release rate from litter and by the total amount of litter that is produced per unit ground area (Gosz, 1981; Aerts and De Caluwe, 1997; Prescott, 2002). The release of nutrients depends on the chemical composition of the litter. As high N, low lignin, low lignin:N and low C:N ratio enabled lantana litter to decompose rapidly beneath lantana canopy. Similar patterns of decomposition were also observed under forest canopy but the *k*-values were lower than lantana canopy and this could be attributed to altered microclimatic condition beneath the lantana canopy.

High N and low lignin is associated with faster decomposition and higher mineralization (Rutigliano et al., 1996; Prescott, 2002). Soil N-mineralization and lignin:N ratio has been shown to be negatively related with each other for the temperate forest species (Scott and Binkley, 1997). Lignin:N ratio of foliage litter has been significantly correlated with the rate of decomposition (Taylor et al., 1991) and net mineralization (Scott and Binkley, 1997) in the Rocky Mountain forests. Rawat et al. (1994) also reported that N content of lantana is higher than other native species within its habitat. Litter of two exotics, *Buddeleja asiatica* and *Myrica faya*, are also N-rich and decomposes easily compared with native litter, leading to increased soil nutrients beneath the exotics (Matson, 1990). Invasive species often maintain higher concentration of leaf N (Vitousek et al., 1987; Nagel and Griffin, 2001; Ashton et al., 2005) and consequently, are expected to decompose more rapidly and release more N to the soil than native species.

Higher N beneath the lantana canopy and lower N beneath the forest canopy during the start of the experiment, which subsequently increased at both the locations at the end of the experiment. This relation was observed because lantana canopy must have started altering the nutrients beneath when it first invaded, suggesting lantana litter inputs may drive temporal nutrient shift beneath its canopy.

The accumulation of soil N closely follows that of soil organic matter (in the form of litter) because, on an average, about 99% of the N in terrestrial ecosystem is organically bound (Rosswall, 1976; Raghubanshi, 1992). Soil N availability varies widely depending upon the availability of readily decomposed nitrogenous compounds (Morecroft et al., 1992) and also on organic inputs (Boyle and Paul, 1989). High N content of lantana litter favors faster decomposition and early availability of the N. All the factors influence the availability and processing rates of limiting nutrients such as N (Klopatek, 1987). Similar results have also been observed under red alder (*Alnus rubra* Bong.) species (Cole et al., 1995), as invasive vegetation exerts an influence on N-mineralization through litter quality and quantity inputs (Berg and Staaf, 1981). A recent review by Ehrenfeld (2003) also suggested that in most cases, but certainly not all, that litter of invasive species decomposes more rapidly than native species.

N-mineralization in forest soil is affected by fluctuation in soil moisture (Myers et al., 1982) content as well as differences in C and N availability (Zushi, 2003) which may be the cause for altered ammonification and nitrification rates beneath lantana and forest canopy. The increase in ammonification and nitrification under high lantana canopy drove the shift in N-mineralization rates. Increase in N-mineralization rate with increasing lantana cover reflects the altered situation created by lantana invasion.

These results suggest that lantana canopy alters the soil N dynamics successively with increasing cover. Higher turn over rates, which reflects the rate of nutrient cycling, was reported for lantana in oak forests (Rawat and Singh, 1988). Rawat et al. (1994) also advocated that high turnover rates, high rates of decomposition of litter and efficient translocation of nutrients results in high production value of lantana. Lower *k* constant and favorable chemical composition of litter, enhance the rate of decomposition, increases the N availability, and N-mineralization. Thus, with increasing lantana cover the litter amount increases, escalating the nutrient availability and rate. When the return of N from the decay of litter of invasive species to the soil pool is greater than that of indigenous plants, N availability at the soil surface may increase and the rates of nutrient cycling in invaded areas may rise (Vitousek and Walker, 1989; Witkowski, 1991). The study also reveals that the return of the decomposable material (lantana litter, mixed litter and litter of other species), release of nutrients by decomposition and mineralization, and nutrient uptake by the invasive lantana might be tightly coupled in time and space. This coupling is exhibited in the form of a positive relation between N-mineralization and lantana cover. The self-perpetuating nutrient availability due to fast N-mineralization results in more dense proliferation of lantana (Sharma and Raghubanshi, 2006, 2007). Schlesinger and Pilmanis (1998) also reported increase in soil nutrients beneath the shrubby bushes of desert ecosystems and called them as "islands of fertility" which are formed after the alien species invade.

Many studies show increase in N-mineralization rates after invasion of the system by an exotic plant species. N-mineralization rates in soil beneath an invasive plant (*Kochia scoparia*) in short grass steppe was found to be about 40% higher than beneath any other six native species (Vinton and Burke, 1995). Higher rates of N-mineralization were also observed under the exotic grass *Melinis minutiflora* (Asner and Beatty, 1996). Kourtev et al. (1998) also corroborated an increase in soil nitrification rates associated with the exotic species *Berberis thunbergii* and *Microstegium vimineum* in the deciduous forest of New Jersey. Ashton et al. (2005) and Funk (2005) demonstrated that invasion of nonnative species alters the soil pools and processes in the mixed deciduous forest of USA and Hawaiian Montane rainforest, respectively.

It may be argued here that with the increasing lantana cover the bush size increases, subsequently increasing the N rich lantana litter inputs which overall leads to altered soil moisture beneath the bushes and thus creates a favorable environment for N-mineralization. This escalation of nutrients (N and C) beneath the lantana canopy may be the cause of its dense proliferation. Levine et al. (2006) opined that such increase in nutrients beneath the invader positively affect the growth and spread in the form of "pushed" and "pulled" invasion. At this juncture we may conclude that the invasion of lantana in the dry deciduous forest is altering the soil N pools and processes positively and further studies warrants examining to look in how the soil microbial communities are altered after the invasion, to reveal that a coupling might exists between the above ground and below ground communities in an invaded forest.

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